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ABSTRACT

A systematic sampling design employing baited hoop traps was used to estimate abundance and/or indices of abundance and mean lengths of burbot *Lota lota* in one section each of the Tolovana, Tanana, Chena, Nenana, and Yukon rivers, and in Goldstream Creek. Sampling was conducted during ice-free periods from June through October 1991. Abundance of fully recruited burbot (450 millimeters total length and larger) was estimated with mark-recapture experiments in a 48 kilometer section of the Tolovana River (abundance = 6,047 burbot; standard error = 2,240) and in a 24 kilometer section of the Chena River (abundance = 1,702 burbot; standard error = 330). Mean catch-per-unit of effort of fully recruited burbot per 24 hour set was estimated for five of the six river sections and ranged from 0.41 (standard error = 0.03) during the second sampling event in the Tolovana River section to 1.04 (standard error = 0.06) during the first sampling event in this same section. Mean length of fully recruited burbot was estimated in all six river sections, and ranged from 534 millimeters total length (standard error = 4) in the Tanana River section to 750 millimeters total length (standard error = 8) in the Yukon River section.

KEY WORDS: burbot, *Lota lota*, abundance, hoop traps, mean length, catch-per-unit of effort, movement, mark-recapture experiment.

INTRODUCTION

Burbot *Lota lota* are a sought-after sport fish by anglers in Alaska. Annual state-wide harvests of burbot increased dramatically in the early 1980's and exceeded 27,000 burbot in 1985 (Mills 1986). Conservation concerns brought on by increasing harvests prompted the Alaska Board of Fisheries to implement more restrictive regulations governing seasons, daily bag and possession limits, and methods and means for many lacustrine fisheries. The largest burbot fishery in the Arctic-Yukon-Kuskokwim region in recent years has been in the Tanana River and its tributaries. Harvests from this fishery have ranged from 3,000 to 5,000 fish annually since 1981, and have averaged between 18 and 46% of the total state-wide lake and river burbot harvest during these same years (Mills 1982-1991).

In response to increasing harvests, and because of limited information available in the scientific literature regarding life history characteristics and population dynamics of riverine burbot, a stock assessment program of Tanana River populations was initiated by the Alaska Department of Fish and Game in 1983. The objectives of this research program have been to determine biological characteristics such as size, age, and density distributions, identify migratory behavior, examine reproductive characteristics, and to monitor the sport fishery. The purpose of the research described in this report is to supplement existing information regarding density distributions and size compositions of burbot in various river sections within the Yukon and Tanana River drainages. Four of the six sections sampled during this study have also been sampled in past years (Evenson 1989-1991). The sample sections of the Tanana and Chena rivers represent areas where substantial sport harvest occurs, whereas minimal harvest occurs within the other four sections (Appendix A). However, because substantial movements occur throughout the system, accurate stock assessment requires that sections throughout the drainage be sampled. The specific project objectives of this investigation were to estimate:

1. abundance of all burbot 450 mm total length (TL) and longer in one 48 km section of the Tolovana River and one 24 km section of the Chena River;

2. mean catch-per-unit of effort (CPUE) for all burbot 450 mm TL and longer in these two sections and in one 24 km section each of the Tanana, Nenana, and Yukon rivers; and,

3. mean length of all burbot 450 mm TL and longer captured in these five sections.

In addition to the above objectives, an estimate of mean length for all burbot captured in Goldstream Creek was calculated.

METHODS

Study Area

Sampling was conducted in one section each of the Tolovana River, the Chena River, the Tanana River, the Nenana River, Goldstream Creek, and the Yukon River (Figure 1, Appendix A).

Gear Description

Burbot were captured in hoop traps 3.05 m long with seven 6.35 mm steel hoops (Figure 2). Hoop diameters taper from 0.61 m at the entrance to 0.46 m at the cod end. Each trap has a double throat (tied to the second and fourth hoops) which narrows to an opening 10 cm in diameter. All netting is knotted nylon woven into 25 mm bar mesh, bound with No. 15 cotton twine, and treated with an asphaltic compound. Each trap is kept stretched with two sections of 19 mm PVC pipe attached by snap clips to the end hoops.

Hoop traps were baited with cut Pacific herring *Clupea harengus* placed in perforated plastic containers. One end of a 5 to 10 m section of polypropylene rope was tied to the cod end of each trap, while the other end was tied off to shore. The traps then fished on the river bottom near shore with the opening facing downstream. An outboard-powered riverboat was used to set, move, and retrieve the traps.

In Goldstream Creek, sampling was conducted using the hoop traps described above and two different types of fyke traps. The fyke traps were set as part of a northern pike *Esox lucius* sampling program, and burbot were caught incidentally.

The first trap was 2.5 m x 1.8 m x 4.5 m with 7 mm bar mesh. Attached to this trap were two 15 m x 3 m wings with 7 mm bar mesh. This trap was set facing downstream with the wings set at a slight downstream angle, such that the entire channel was blocked off.

The second traps were 1.2 m x 1.2 m x 3.5 m with 25 mm bar mesh. Two wings 7 m x 3 m were attached to the traps. The traps were set along side channel areas of the creek.

Study Design

With the exception of the Goldstream Creek section, the sampling protocol was similar for all river sections except the dates of sampling, duration and number of sampling events, and amount of effort were variable for each river section (Table 1). In five of six river sections, a systematic design was used whereby traps were set along both shores at near equal intervals beginning at the most downstream end of the section and progressing to the most upstream end of the section. All traps were fished for approximately 24 hours, traps were rebaited, and were moved to a slightly upstream area. All trap locations were marked on 1:63,360 USGS maps and were recorded to the nearest km. All burbot captured were measured for total length (TL) to the nearest mm, and were tagged using individually numbered Floy internal anchor

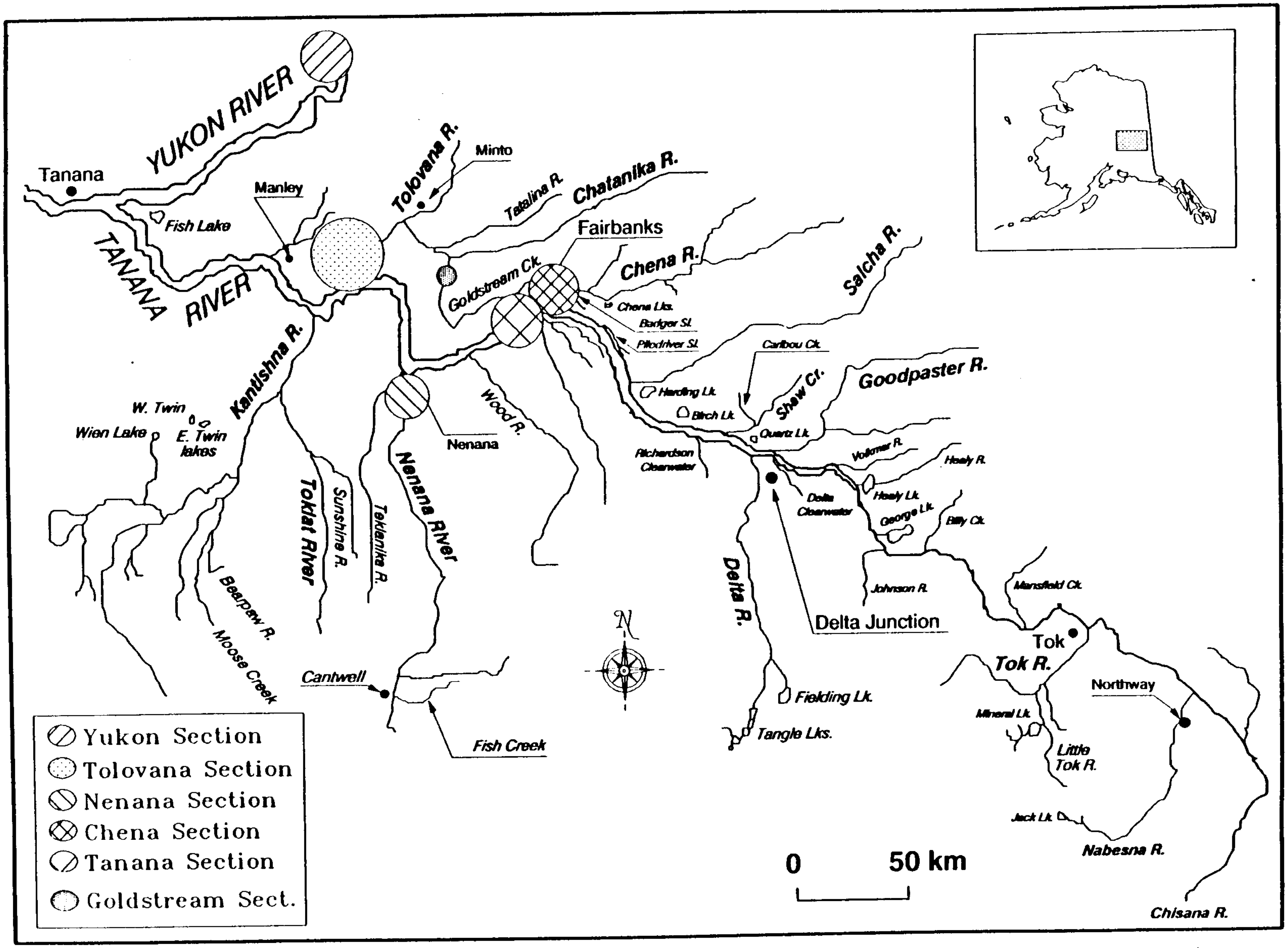

Figure 1. Map of the Tanana River drainage showing sampling locations during 1991.

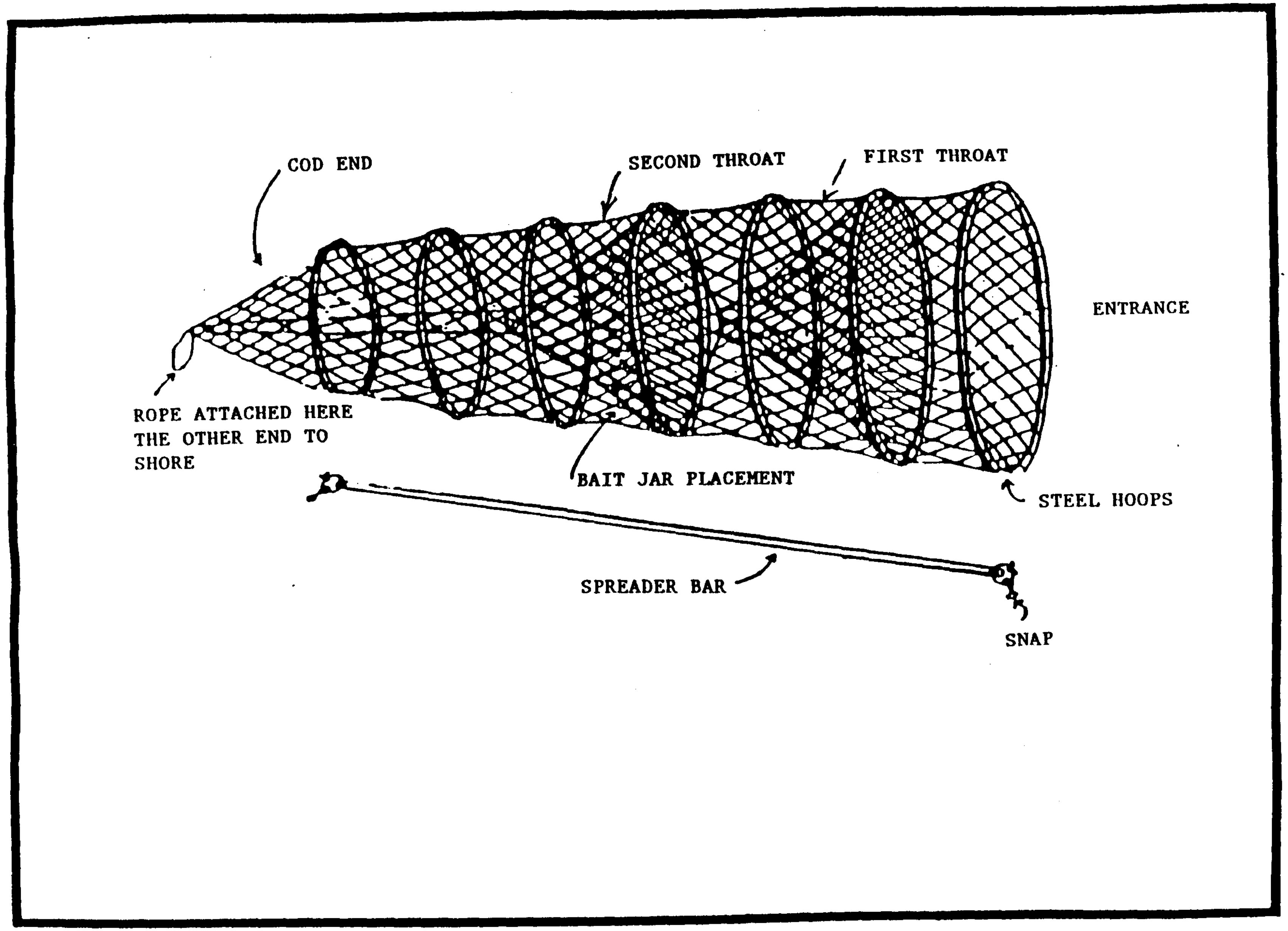

Figure 2. Diagram of hoop trap gear used to capture burbot.

Table 1. Summary of sampling events conducted during 1991.

Sample Area and Objective	Dates of Sampling	River Kilometers Sampled[a]	Number of Traps Fished	Trap Density (Traps per Day per river km)
	Goldstream Creek Section			
Mean Length	4/23 - 5/8	5-10	N/A[b]	N/A[b]
	Tolovana River Section			
Abundance (Mark Event)	6/12 - 6/19	0-48	570	1.5
CPUE				
Mean Length				
Abundance (Recapture Sample)	6/26 - 7/3	0-48	568	1.5
CPUE				
Mean Length				
	Tanana River Section			
CPUE	7/11 - 7/12	336-360	310	3.2
Mean Length	7/16 - 7/17			
	Nenana River Section			
CPUE	8/20 - 8/23	0-24	242	2.5
Mean Length				
	Chena River Section			
Abundance (Mark Event)	8/27 - 8/30	0-24	268	2.8
CPUE				
Mean Length				
Abundance (Recapture Event)	9/4 - 9/7	0-24	248	2.6
CPUE				
Mean Length				
	Yukon River Section			
CPUE	10/1 - 10/4	0-24[a]	173	1.8
Mean Length				

[a] All measurements for a given river section were measured in kilometers upstream from the river mouth, except for the Yukon River section which was measured in kilometers downstream from the Dalton Highway Bridge.

[b] Not applicable. A variety of gear types were used in this sampling event, and a standardized hoop trap design was not used.

tags. All fish captured in the Chena and Tolovana river sections were given a unique fin-clip corresponding to the sampling event (marking or recapture) and the area within the section (upper, middle, or lower). All fish were released at the capture site.

Abundance Estimation

The methodology developed to estimate abundance of burbot in rivers of interior Alaska is based on the Petersen method (described in Seber 1982), but is often modified due to the movement behavior of burbot between sampling events, and the inherent size selective bias of the hoop trap gear. Segregation of the study area into three divisions is used to quantify movements, and long study areas are chosen to help minimize emigration and immigration of fish during the experiment. Size selectivity can usually be identified (using statistical procedures described below) and corrected for, or full recruitment for all burbot 450 mm TL and larger can be inferred based on findings from previous studies (Evenson 1988; Parker et al. 1987, 1988; Bernard et al. 1991).

Sample sizes were determined as described by Robson and Regier (1964). Abundance prior to the sampling events was estimated for the Chena River section based on an estimate obtained during 1990 for the same section. This estimate was also used for a pre-sampling estimate of abundance in the Tolovana River section, as abundance had not been estimated previously for this section. The number of traps required to attain these sample sizes were based on historic estimates of abundance for both sections.

In experiments conducted during 1991 in the Chena River and Tolovana River sections, there was a single sampling event constituting the marking sample, a short hiatus, and a single sampling event constituting the recapture sample. In the Chena River section, the marking sample was conducted over a four day period, the hiatus lasted three days and the recapture sample was conducted over a four day period. In the Tolovana River section, the marking sample was conducted over an eight day period, there was a hiatus lasting five days, and the recapture sample was conducted over an eight day period. Approximately equal effort (number of traps set) was expended during each event in both experiments (Table 1). Each section was divided into three divisions of equal length corresponding to the lower, middle, and upper reaches of the section.

The assumptions for an unbiased estimate of abundance using mark-recapture methods (Seber 1982) in this experiment are:

1) the population is closed (no change in the number of burbot in the population during the estimation experiment);

2) all burbot have the same probability of capture during the first sample <u>or</u> in the second sample <u>or</u> marked and unmarked burbot mix completely between the first and second samples;

3) marking of burbot does not affect their probability of capture in the second sample; and,

4) burbot do not lose their mark between sampling events.

Assumption 1 was not tested directly, but migration of fish out of or into the river section was inferred from analysis of movements of recaptured burbot within and among the three divisions for each sampling event. A recapture matrix was created in which the rows corresponded to the capture location and the columns corresponded to the recapture location. If a high proportion of fish were noted as moving a distance greater than the length of the individual divisions, then the assumption that the population is closed to immigration and emigration was considered false. Other factors possibly contributing to the failure of assumption 1 (mortality and growth recruitment) were assumed to be negligible. The short duration of the experiments should have prevented appreciable mortality and growth from occurring.

Equal probability of capture during each sampling event by size was tested with two Kolmogorov-Smirnov two-sample statistical tests. The first test compared the length frequency distributions of recaptured burbot with those captured during the marking sample. The second test compared the length frequency distributions of burbot captured during the marking sample with those captured in the recapture sample. The results of these two tests determined the methodology used to alleviate bias in abundance estimation (Appendix B).

Equal probability of capture by river division was tested with contingency table analysis. The possibly size-stratified data from the recapture sample were then arranged in a 3 x 2 contingency table. The two columns corresponded to the number of burbot recaptured and the number of burbot not recaptured during the second sample. The three rows corresponded to the three river divisions within a sample section. Null hypotheses of these tests are either marked fish mix completely with unmarked fish <u>or</u> all burbot in the marking sample have an equal probability of capture in all three divisions. If the test was not significant ($p > 0.05$), it was not known whether one or both of the two hypotheses were valid, but at least one was, which satisfied the conditions for assumption 2.

Marking and handling burbot should not affect their probability of recapture (assumption 3). It is not known whether the hiatus in these experiments (five and three days for the Tolovana and Chena sections, respectively) was ample time to reverse any behavioral changes ("trap happiness", "trap shyness", or physiological stress) which may have been associated with the experience of being captured. However, Bernard et al. (1991) indicated that capture induced behavior of burbot in hoop traps waned within several months of capture, and indicated that there was likely a rapid recovery from their fish capture experience.

Because double marking was employed, no tag loss should have occurred (assumption 4) unless fish without tags were not inspected for fin clips. To minimize the possibility of this occurring, a unique fin-clip was also given to all fish collected during the recapture sample.

If these assumptions were all met, and if inter-area movement was observed in low proportions, then the modified Petersen estimator of Bailey (1951, 1952) was used to estimate abundance:

$$\hat{N} = \frac{M\ (C + 1)}{(R + 1)} - 1 \tag{1}$$

$$V(\hat{N}) = \frac{(M + 1)(C + 1)(M - R)(C - R)}{(R + 1)^2(R + 2)} \tag{2}$$

where: M = the number of burbot marked and released alive during the first sample;

C = the number of burbot examined for marks during the second sample;

R = the number of burbot with marks (from the first sample) collected during the second sample; and,

$\hat{N}$ = the estimated abundance of burbot during the first sample.

Alternatively, if significant inter-area movement of fish in the study section was observed between the marking (first event) and recapture (second event) samples, a modified Petersen estimator (Evenson 1988) was used to compensate for the movement of marked burbot out of the study section. The additional assumptions necessary for accurate use of this estimator are:

5) no burbot tagged in the midstream division migrate out of the study section; and,

6) a single process causes upstream movement, and a single process causes downstream movement.

The modified Petersen estimator that accounts for movements of tagged fish is:

$$\hat{N}^{*} = \frac{\{\ M_1(1-\hat{\Theta}_d) + M_2 + M_3(1-\hat{\Theta}_u)\ \}\ \{C + 1\}}{R.. + 1} \tag{3}$$

where:

M_x = the number of burbot marked in the first event in division x (x = 1, 2, and 3 for the downstream, midstream, and upstream divisions, respectively);

R = the number of burbot recaptured during the second sample;

Θ_z = the probability that a burbot will move out of a division in the z direction (upstream or downstream);

C = the catch during the second sample; and,

$\hat{N}^*$ = the abundance of burbot in <u>all</u> divisions at the start of the second sample.

The probabilities of movements are estimated by:

$$\hat{\Theta}_d = \frac{M_2(R_{32} + R_{21})}{R_{2.}(M_3 + M_2)}; \tag{4}$$

$$\hat{\Theta}_u = \frac{M_2(R_{12} + R_{23})}{R_{2.}(M_1 + M_2)} \tag{5}$$

where:

R_{xy} = the number of burbot that were marked in division x during the first sample and were recaptured in division y during the second sample; and,

$R_{2.}$ = the number of burbot that were marked in the midstream area during the first sample and were recaptured during the second sample.

Variances of these estimates (equations 3, 4, and 5) were calculated by bootstrapping (Efron 1982). First, capture history of each fish was recorded by study area. A capture was denoted with the study division (1 for downstream, 2 for midstream, and 3 for upstream area). If the fish was not captured, this was denoted by a zero. The total number of capture histories was the sum of fish marked in the first sample plus the total number of fish examined in the second sample minus two times the number of fish seen in both samples (recaptures). These capture histories were then resampled with replacement 1,000 times by computer. Each replication of the estimation experiment involved sampling of "the total number of capture histories" and then calculating an abundance estimate (and probabilities of movement). After 1,000 replications, the mean and variance (Snedecor and Cochran 1980) were calculated for all replicates.

<u>Catch-per-Unit of Effort</u>

Mean CPUE (defined as burbot per net-night) for each river section and its associated variance were calculated from the number of burbot caught per net-night for all traps set during each sampling period based upon the following equations from Wolter (1984):

$$\overline{CPUE_c} = \bar{X}_c = t^{-1} \sum_{h=1}^{t} X_{ch}; \tag{6}$$

$$V[\overline{CPUE_c}] = \frac{\sum_{h=2}^{t} [X_{ch} - X_{ch-1}]^2}{2t[t-1]} \qquad (7)$$

where:

X_{ch} = catch of burbot of size class c in hoop trap h;

t = the total number of hoop traps in a river section; and,

s = the set number such that s = 1 to t in order with i = 1 the most downstream set and i = t the most upstream.

Typically, full recruitment to the hoop trap gear used in this study begins at 450 mm TL (Evenson 1988; Bernard et al. 1991). In some cases however, large burbot (greater than 800 mm TL) are caught less frequently (Bernard et al. 1991). Therefore, mean CPUE was estimated for three size classes (less than 450 mm TL, 450 to 800 mm TL, and greater than 800 mm TL).

As stated earlier, more than one sampling event was conducted during the mark-recapture estimates for the Chena and Tolovana sections. If both events were considered unbiased (for length), an estimate of mean CPUE for all events in each of these sections was:

$$\overline{CPUE} = \sum_{c=1}^{d} W_c \, \overline{CPUE_c}; \qquad (8)$$

$$V[\overline{CPUE}] = \sum_{c=1}^{d} W_c^2 \, V[\overline{CPUE_c}] \qquad (9)$$

where:

$W_c = h_p/h$ = the number of hoop traps set in sampling event p divided by the total number of hoop traps set in all d sampling events.

<u>Length Composition</u>

Due to selectivity of the gear, estimates of mean length were stratified by length categories. For all river sections, mean length for burbot in each of three length categories (less than 450 mm, 450 to 799 mm, and 800 mm TL and larger) was calculated as:

$$\bar{l}_a = \sum_{b=1}^{n} \frac{l_{ab}}{n_a}; \qquad (10)$$

$$V[\bar{l}_a] = \sum_{b=1}^{n} \frac{(l_{ab} - \bar{l}_a)^2}{n_a(n_a - 1)} \tag{11}$$

where:

l_{ab} = length of burbot b in length category a; and,

n_a = number of samples in length category a.

Unless determined otherwise, only the estimate of mean length for burbot 450 to 800 mm TL is considered unbiased. In the Tolovana and Chena sections statistical testing (described in the abundance estimation section) determined which sampling events were unbiased. If more than one event was considered unbiased, then length data were combined and mean lengths were calculated as:

$$\bar{l}_t = \sum_{a=1}^{k} W_a \bar{l}_a; \tag{12}$$

$$V[\bar{l}_t] = \sum_{a=1}^{k} W_a^2 V[\bar{l}_a] \tag{13}$$

where:

$W_a = n_a / \sum_{a=1}^{k} n_a$ = number of samples in event a divided by the total number of samples in all k events.

RESULTS

Abundance Estimate: Tolovana River Section

A total of 598 burbot 450 mm TL and larger were caught and marked during the first sample, and a total of 234 were caught and examined for marks during the second sample. Of those collected during the second sample, 13 had marks from the first sample (recaptures). Three immediate mortalities were recorded during both events for an overall mortality rate of 0.4%. No tags were lost during the sampling period.

Test for Size Selectivity:

Kolmogorov-Smirnov two sample tests comparing a) cumulative distribution functions (CDF) of all fish collected during the first sample and all recaptured fish collected during the second sample; and, b) CDF of all fish collected during the first event and all fish collected during the second event indicated that there was size-selectivity during both events (test a, DN = 0.20, $P = 0.71$; test b, DN = 0.17, $P < 0.01$; Figure 3). Although test a was not statistically significant, the low power of the test resulting from the small recapture sample, and the observed difference in the two length frequency distributions (Figure 3) indicates that burbot captured during the second event were significantly smaller than burbot captured during the first event.

Test for Equal Probability of Capture and Complete Mixing:

Contingency table analysis indicated that marked-to-unmarked ratios were not significantly different among all three river sections ($\chi^2 = 4.44$, $df = 2$, $0.010 < P < 0.25$). Examination of recapture rates indicated that there was a relatively low probability of recapture in the downstream section (Table 2).

Test for Significant Movement:

Inter-section movement of marked fish between sampling events did occur (Table 2). Eight of the 13 recaptured fish moved out of the division in which they were tagged (all moved downstream). One recaptured fish was documented as moving more than one division downstream (moved from upper to lower river division). The greatest movement of any recaptured fish was 20 km downstream, while the mean distance moved for all recaptured fish was 9 km downstream (Figure 4).

Estimate of Abundance:

The results of the above tests indicated that there was size-selectivity during at least one of the two sampling events, and that there was significant movement out of the study area between sampling events. This information suggests that the modified Petersen model of Bernard (Evenson 1988) be used to estimate abundance in order to relieve the bias associated with emigration from the study section between sampling events. The protocol described in Appendix B suggests that the estimate be stratified by length to relieve the bias associated with size-selectivity during one or both sampling events. However, the low number of recaptured burbot obtained did not warrant any size-stratification.

The estimated abundance of burbot 450 mm TL and longer in this 48 km river section using resampling techniques was 6,047 (*SE* = 2,240; Table 3, Figure 5), or a density of 126 burbot per km. This compares to a point estimate of 6,793, giving a statistical bias of 746 (11%). This estimate was 40% lower than the Bailey modification (Bailey 1951, 1952) which estimated abundance to be 10,055 (*SE* = 2,513). Probabilities of movement were calculated to be 0 (*SE* = 0) for upstream and 1.55 (*SE* = 0.52) for downstream (Table 3, Figure 5). This further supported the hypothesis that there was significant movement out of the study area most likely in the downstream section.

<u>Abundance Estimate: Chena River Section</u>

A total of 213 burbot 450 mm TL and larger were caught and marked during the first sample, and a total of 174 were caught and examined for marks during the second sample. Of those collected during the second sample, 21 had marks from

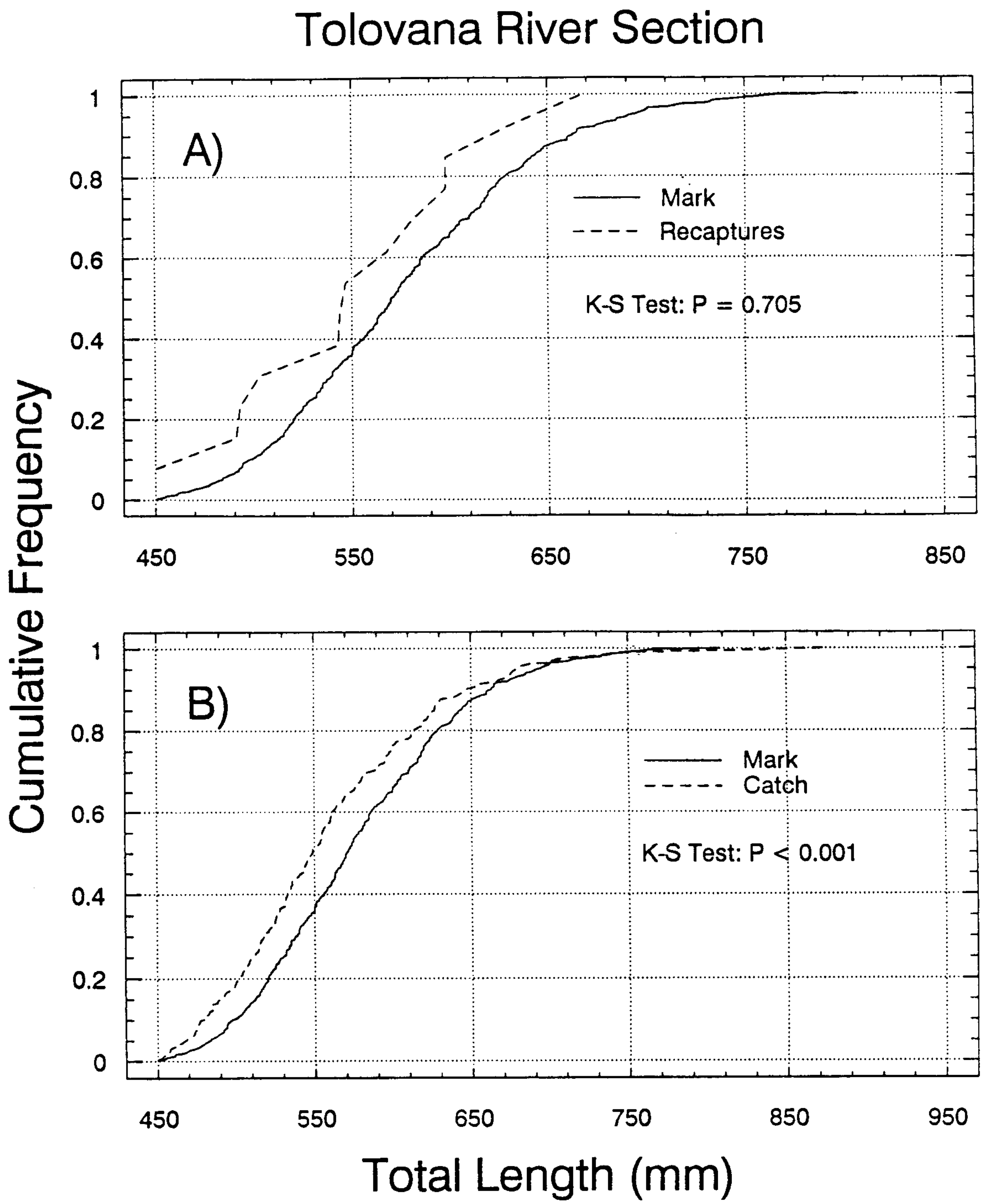

Figure 3. Cumulative length frequency distributions of burbot (≥ 450 mm TL) captured in the Tolovana River section comparing lengths of all burbot captured during the marking sample to: A) lengths of all recaptured burbot; and, B) lengths of all burbot captured during the second event.

Table 2. Capture histories of all burbot (≥450 mm TL) examined during the mark-recapture experiment in the Tolovana River section during 1991.

River Division Where Marks Were Released	River Division Where Marks Were Recaptured: Lower	Middle	Upper	Total	Number Marked	Number Not Recaptured	Recovery Rate
Lower	1	0	0	1	220	219	0.5%
Middle	2	2	0	4	191	187	2.1%
Upper	1	6	1	8	187	179	4.4%
Total	4	8	1	13	598	585	2.2%
Unmarked Burbot During Recapture Sample	44	97	80	221			
Total Burbot During Recapture Sample	48	105	81	234			

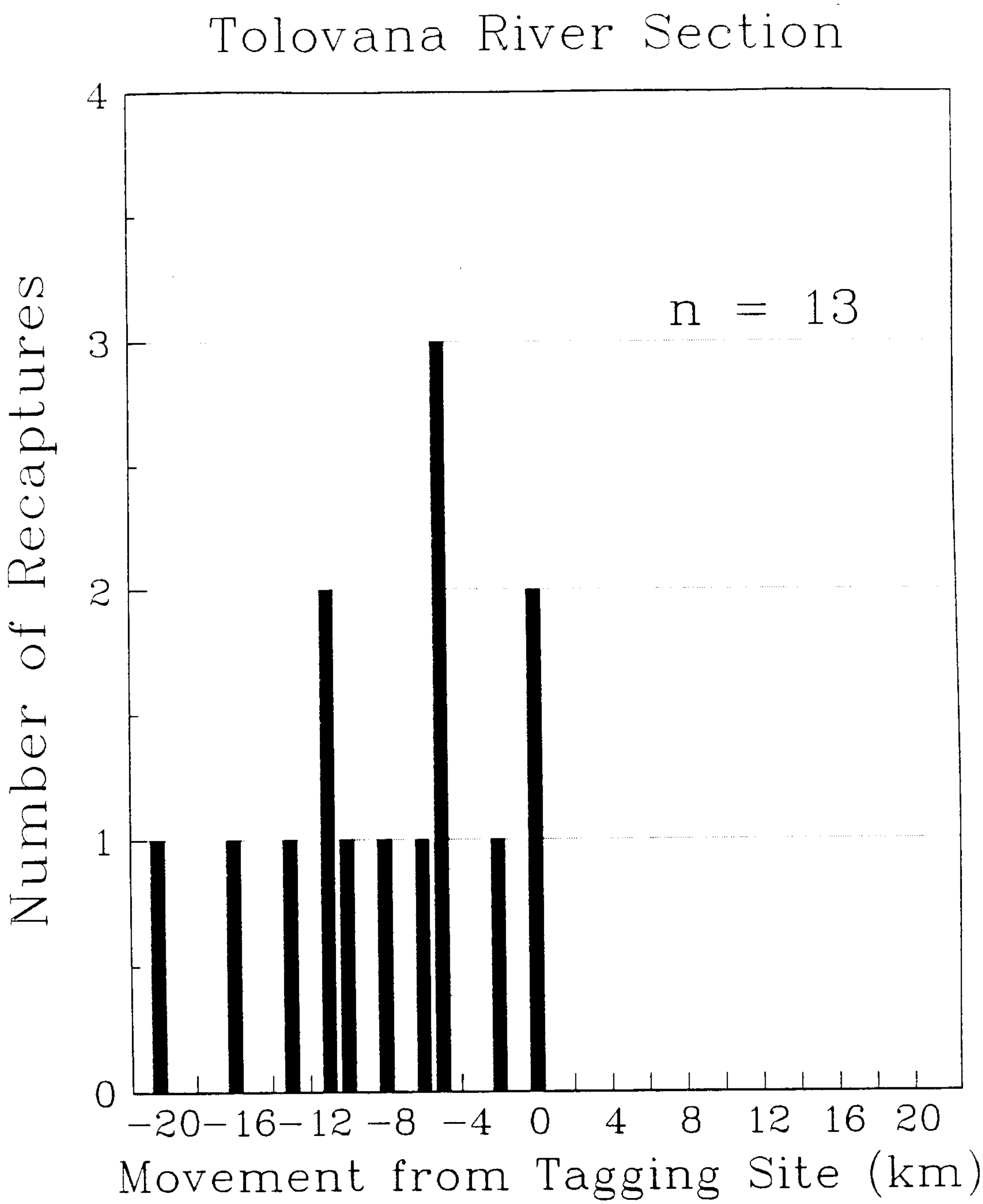

Figure 4. Movements of 13 recaptured burbot caught during the mark-recapture experiment in the Tolovana River section during 1991.

Table 3. Abundance estimates of all burbot (≥ 450 mm TL) in the Tolovana River section during 1991.

Parameter	Calculated or Known Quantity	Bootstrap Estimate
M_1	220	220
M_2	191	192
M_3	187	187
C	234	234
R..	13	13
R_{12}	0	0
R_{23}	0	0
R_2	4	4
R_{21}	2	2
R_{32}	6	6
Θ_u	0	0
SE	Unknown	0
Θ_d	1.01	1.55
SE	Unknown	0.52
$\hat{N}$ (Evenson 1988)	6,793	6,047
SE	Unknown	2,240
$\hat{N}$ (Bailey 1951,1952)	10,055	
SE	2,513	

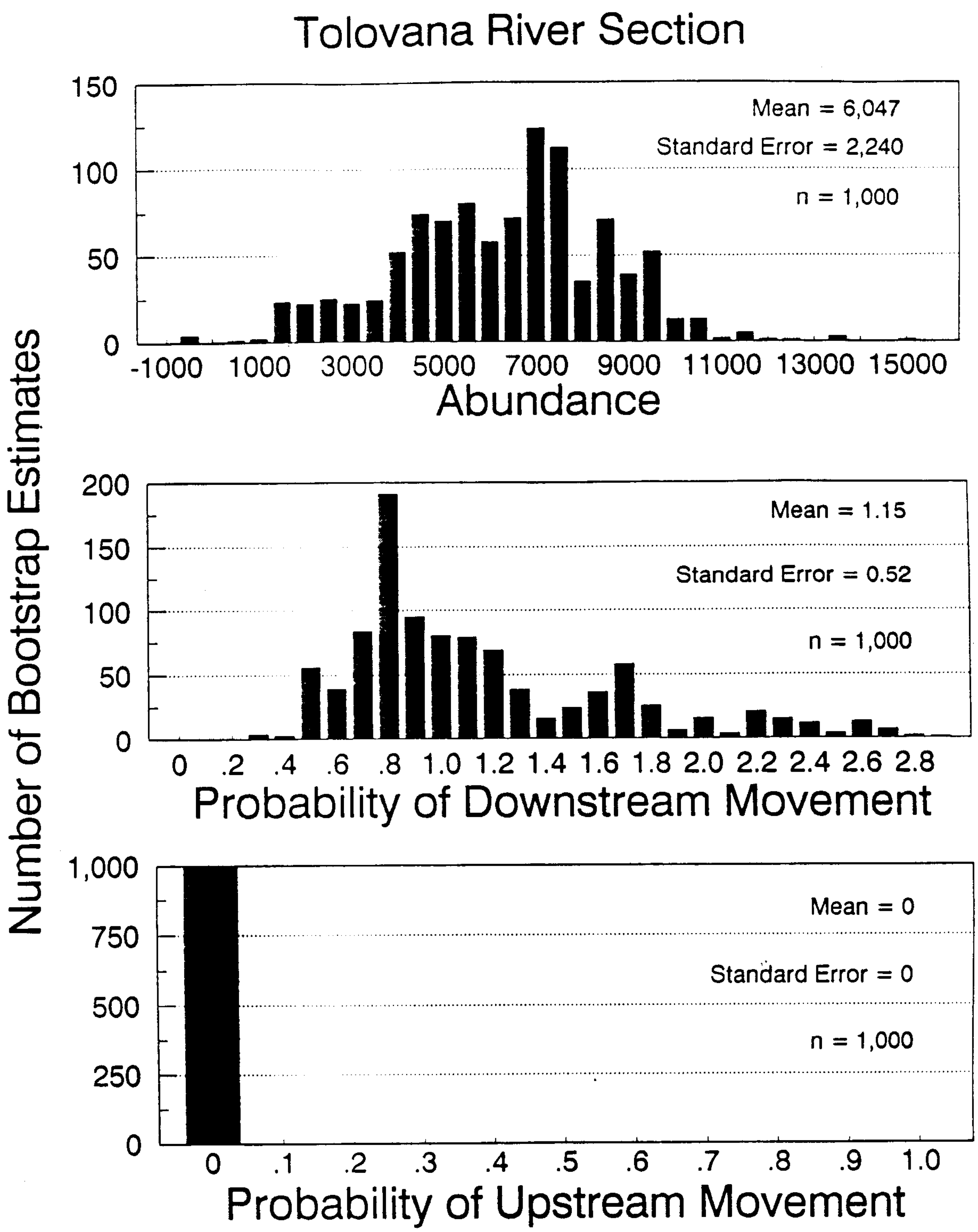

Figure 5. Distributions of 1,000 bootstrap samples used to estimate abundance and probabilities of downstream and upstream movement during the mark-recapture experiment in the Tolovana River section during 1991.

the first sample (recaptures). No capture-induced mortalities were recorded during either event. No tags were lost during the sampling period.

Test for Size Selectivity:

Kolmogorov-Smirnov two sample tests comparing a) CDF of all fish collected during the first sample and all recaptured fish collected during the second sample; and, b) CDF of all fish collected during the first sample and all fish collected during the second sample indicated that there was no size-selectivity during either sample (test a, DN = 0.22, P = 0.63; test b, DN= 0.05 P = 0.85; Figure 6). Length data from both samples were pooled to improve precision of length composition and CPUE estimates.

Test for Equal Probability of Capture and Complete Mixing:

Contingency table analysis indicated that marked-to-unmarked ratios were not significantly different among all three river sections ($\chi^2 = 0.99$, $df = 2$, $0.50 < P < 0.75$). Examination of recapture rates indicated that probabilities of recapture were similar for all sections (Table 4).

Test for Significant Movement:

Inter-section movement of marked fish between sampling events did occur (Table 4). However, only two of the 21 recaptured fish moved out of the division in which they were tagged (one upstream and one downstream). No recaptured fish were documented as moving more than one division upstream or downstream. The greatest movement of any recaptured fish was 15 km upstream, while the mean absolute distance moved for all recaptured fish was 2 km (Figure 7).

Estimate of Abundance:

The above tests indicated that Bailey's (1951, 1952) model was appropriate for estimating abundance. To further investigate whether significant inter-section movement occurred, an estimate using Bernard's model (Evenson 1988) was calculated and compared to the former estimate. Probabilities of movement were 0.16 (SE = 0.22) for upstream and 0.19 (SE = 0.21) for downstream. Fifty-nine of the total 1,000 bootstrap estimates were not used in the calculations of abundance and probabilities of movement. Because only three recaptured burbot were collected which were tagged in river division two (midstream), estimates of $R_{2.}$ (see equations 4 and 5) equal to zero were drawn 59 times out of 1,000. This yielded values of infinity for estimates of θ_d and θ_u, which in turn estimated abundance to be infinity. Estimated abundance of burbot 450 mm TL and larger was 1,702 (SE = 330) using Bailey's model, and was 1,490 (SE = 277) using Bernard's model (Table 5, Figure 8).

A total of seven estimates of abundance have been calculated for five river sections in the Tanana River drainage since 1987 (Table 6). Densities (burbot per river kilometer) range from 71 (SE = 14) in a section of the Chena River to 572 (SE = 41) in a section of the Tanana River. The estimate obtained in the Chena River section during this investigation was nearly identical to an estimate obtained during the same time frame in 1990.

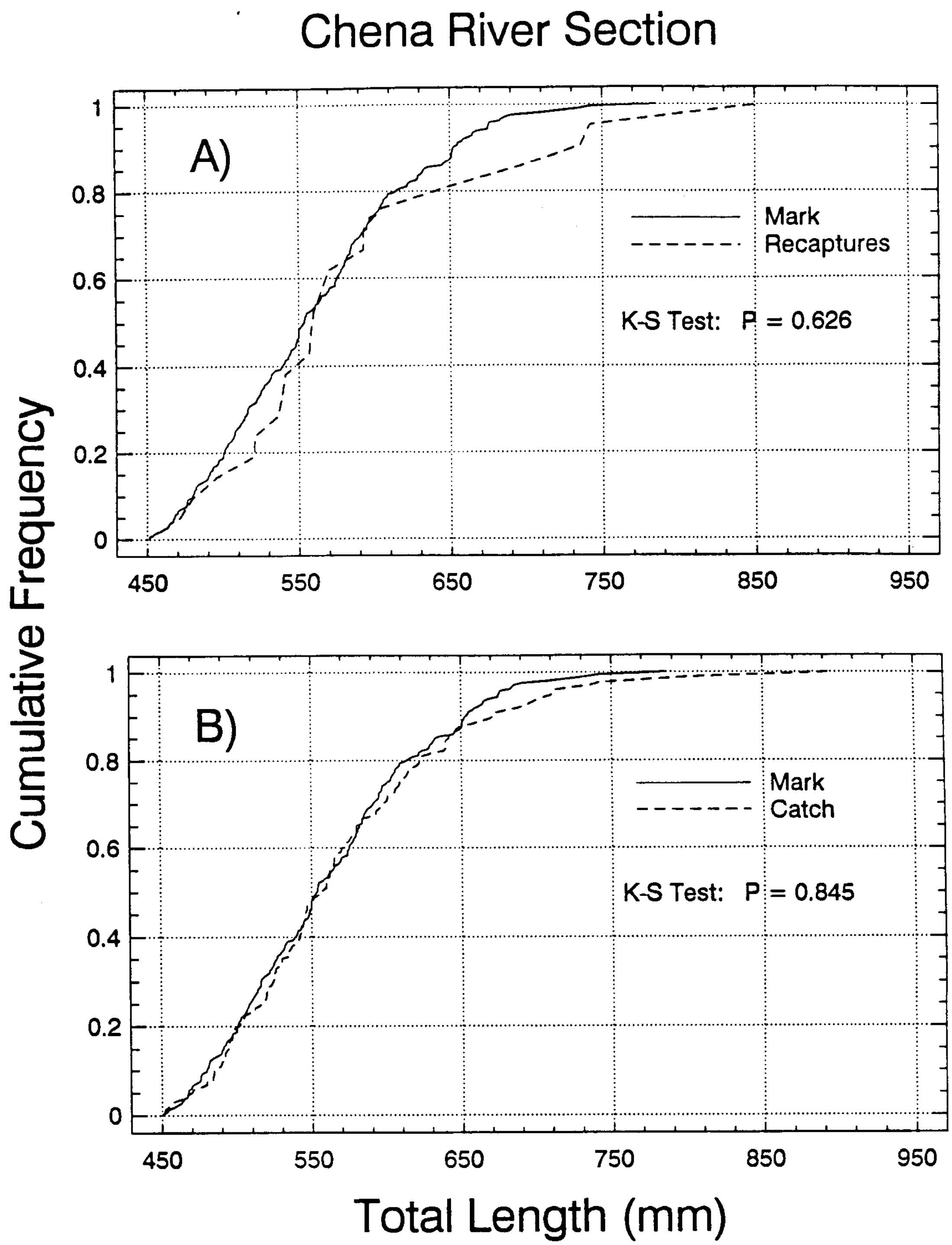

Figure 6. Cumulative length frequency distributions of burbot (≥ 450 mm TL) captured in the Chena River section comparing lengths of all burbot captured during the marking event to: A) lengths of all recaptured burbot; and, B) lengths of all burbot captured during the second event.

Table 4. Capture histories of all burbot (≥450 mm TL) examined during the mark-recapture experiment in the Chena River section during 1991.

River Division Where Marks Were Released	River Division Where Marks Were Recaptured: Lower	Middle	Upper	Total	Number Marked	Number Not Recaptured	Recovery Rate
Lower	9	1	0	10	102	92	9.8%
Middle	0	3	0	3	48	45	6.3%
Upper	0	1	7	8	63	55	12.7%
Total	9	5	7	21	213	192	9.9%
Unmarked Burbot During Recapture Sample	60	52	40	153			
Total Burbot During Recapture Sample	70	57	47	174			

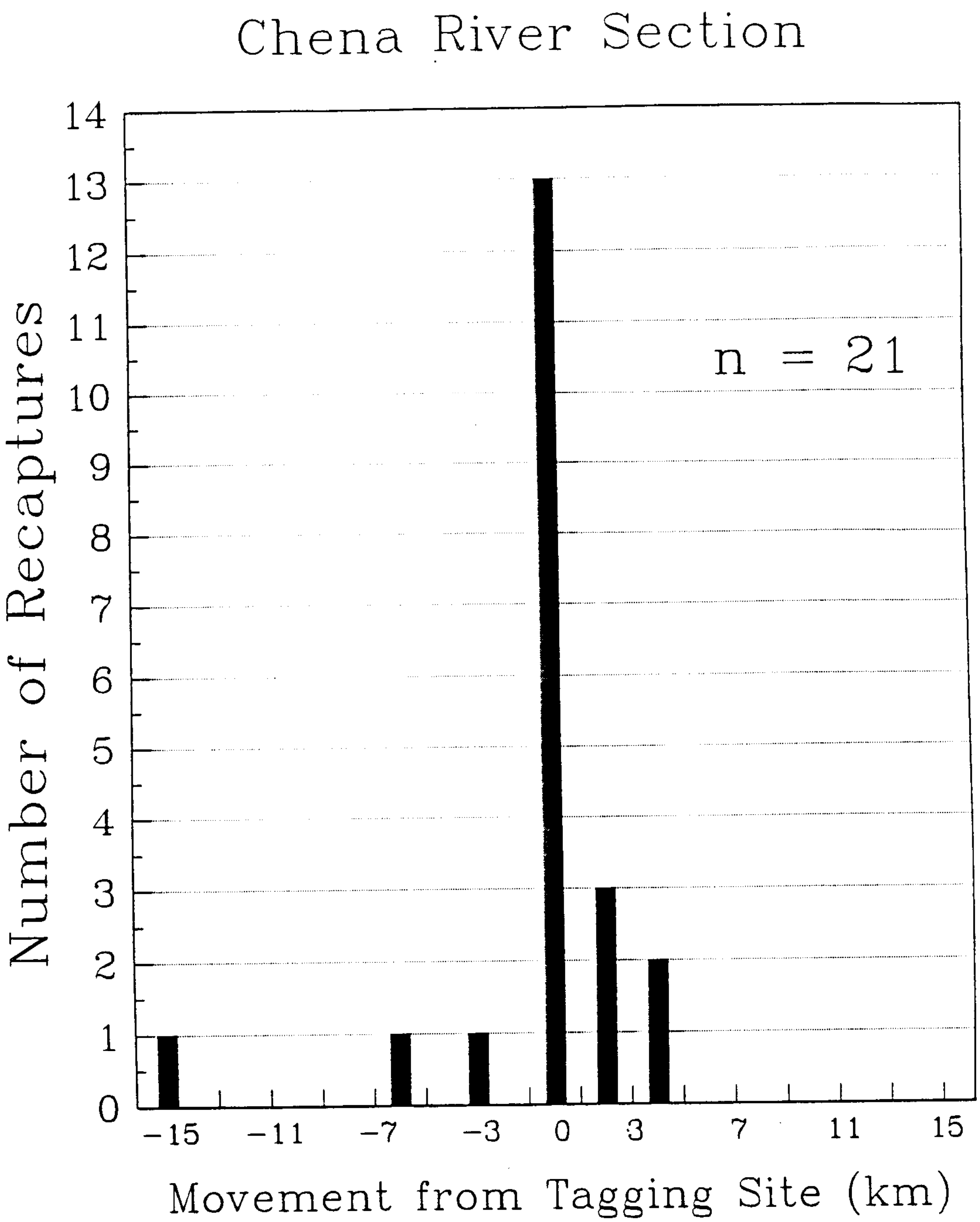

Figure 7. Movements of 21 recaptured burbot caught during the mark-recapture experiment in the Chena River section during 1991.

Table 5. Abundance estimates of all burbot (≥ 450 mm TL) in the Chena River section during 1991.

Parameter	Calculated or Known Quantity	Bootstrap Estimate
M_1	102	103
M_2	48	52
M_3	63	59
C	174	174
$R_{..}$	21	21
R_{12}	1	1
R_{23}	0	0
$R_{2.}$	3	3
R_{21}	0	0
R_{32}	1	1
Θ_u	0.11	0.16
SE	Unknown	0.22
Θ_d	0.14	0.19
SE	Unknown	0.21
$\hat{N}$ (Evenson 1988)	1,596	1,490
SE	Unknown	277
$\hat{N}$ (Bailey 1951,1952)	1,702	
SE	330	

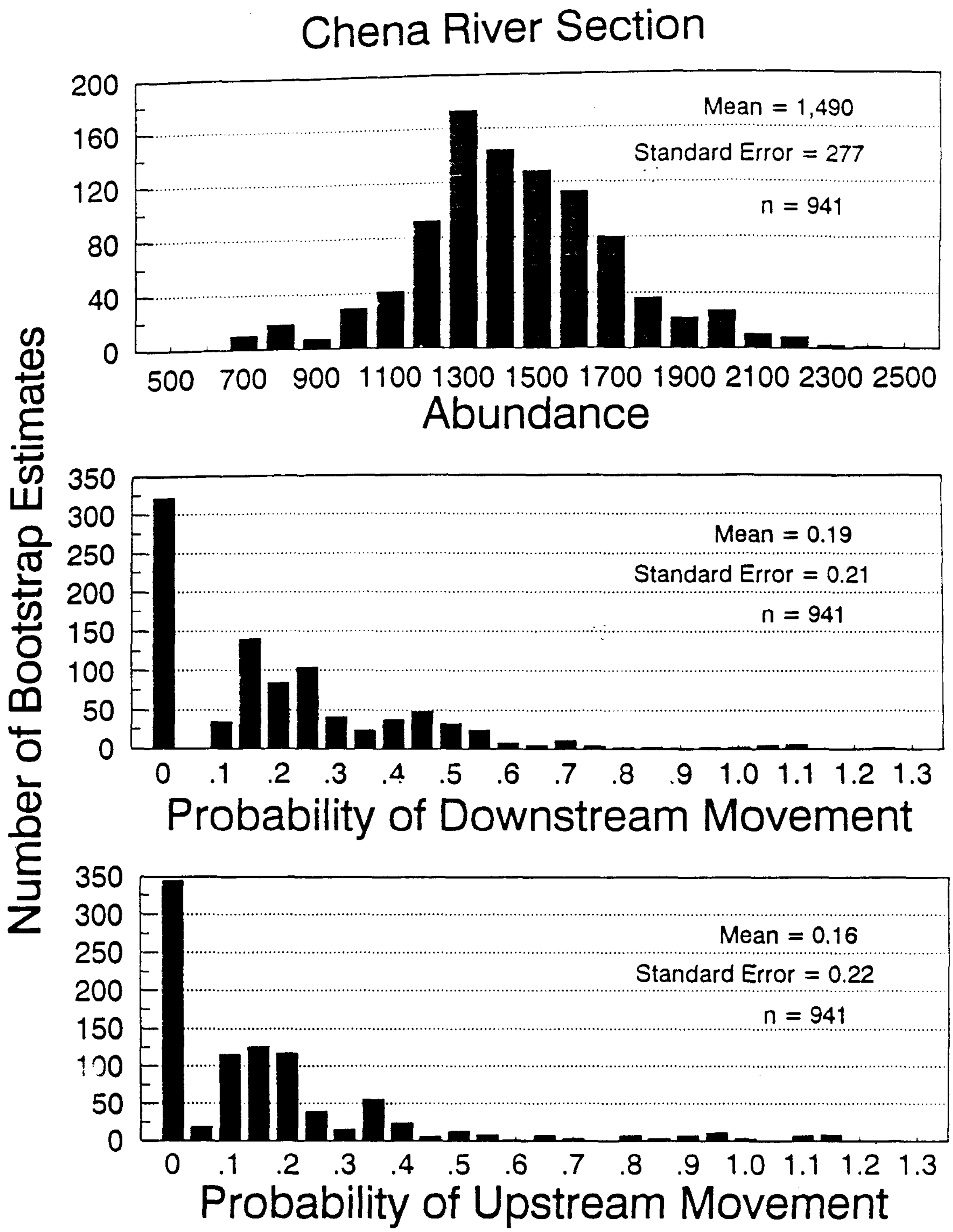

Figure 8. Distributions of 1,000 bootstrap samples used to estimate abundance and probabilities of downstream and upstream movement during the mark-recapture experiment in the Chena River section during 1991.

Table 6. Density and catch-per-unit-effort (CPUE) estimates for burbot 450 mm TL and larger sampled in various river sections throughout the Tanana River drainage.

River	River km Sampled[a]	Year	Density[b]	SE	CPUE[c]	SE	Catchability Coefficient[d]
Tanana	336 - 352	1986[e]	121	28	0.82	ND[i]	0.007
Tanana	336 - 352	1987[f]	159	43	0.86	0.10	0.005
Tanana	582 - 589	1987[f]	572	41	7.02	0.86	0.012
Tanana	888 - 912	1990[g]	93	19	0.93	0.05	0.010
Chena	0 - 24	1990[g]	73	11	0.79	0.03	0.011
Chena	0 - 24	1991[h]	71	14	0.76	0.06	0.011
Tolovana	0 - 48	1991[h]	126	47	0.73	0.03	0.006

[a] River kilometers are measured upstream from the river mouth.
[b] Density estimates are shown as number of large burbot (450 mm TL and larger) per river kilometer.
[c] Catch-per-unit-effort estimates (CPUE) are shown as number of burbot 450 mm TL and larger caught per net-night.
[d] Calculated as CPUE divided by density (from Everhart and Youngs 1981).
[e] From Hallberg et al. (1987).
[f] From Evenson (1988).
[g] From Evenson (1991).
[h] This report.
[i] No data available.

Catch-per-Unit of Effort and Length Compositions

Estimates of mean CPUE (Table 7) and mean length (Table 8) were calculated for three length categories in five river sections. Estimates of mean length were also calculated for all burbot captured in Goldstream Creek. Typically, only the medium length category (450-799 mm TL) is considered unbiased. In the past (Evenson 1988-1990), mean CPUE and mean length have been estimated for all burbot 450 mm TL and larger. For comparative purposes, and because in most sections only few burbot larger than 799 mm TL were captured, estimates of mean CPUE and mean length for all burbot 450 mm TL and larger were also calculated.

Mean CPUE of small burbot (300 to 449 mm TL) was lowest in the Yukon River section (CPUE < 0.01; SE < 0.01), and was highest in the Tanana River section (CPUE = 0.31; SE = 0.04) (Table 9). Estimates of mean length for small burbot were similar in all river sections with the exception of the Yukon River section, in which only one small burbot was captured (Table 10).

Mean CPUE of medium burbot (450 to 799 mm TL) in all sections ranged from 0.41 (SE = 0.03) during the first sampling event in the Tolovana River section to 1.04 (SE = 0.06) during the second sampling event in the Tolovana River section (Table 9). Mean length of medium burbot was smallest in the Tanana River section (mean = 530 mm; SE = 4), and largest in the Yukon River section (mean = 691 mm; SE = 9; Table 10).

Catches of large burbot (> 800 mm TL) were low (mean CPUE ≤ 0.05) in all sections except for the Yukon River section, where 32 large burbot were captured (mean CPUE = 0.19; SE = 0.03).

Four of the six river sections (excluding the Nenana River section and Goldstream Creek section) have been sampled one or more times in previous years. Comparisons of these successive estimates of mean CPUE and mean length are shown in Tables 9 and 10.

DISCUSSION

One of the objectives of this ongoing stock assessment program is to determine relative abundance of burbot throughout the Tanana River drainage by estimating mean CPUE for various river sections using a standardized sampling design. Of major concern in interpreting CPUE estimates is understanding the seasonal fluctuations which occur in most sections. In general, catches tend to be high and variable in the spring (after ice-out) and in the fall (prior to ice-cover). During the summer, catches tend to be lower and more stable. The reasons for these fluctuations are unclear, and the "timing" of the fluctuations seems to vary by river area. In the Tolovana River section sampled during this investigation, catches of large burbot were quite high (CPUE = 1.05) during the marking event in mid-June, but dropped substantially (CPUE = 0.42) during the recapture event one week later. During sampling in the Chena River section during 1990, catches of large burbot were low (CPUE = 0.07) in mid-June, but by early September were substantially higher

Table 7. Catch-per-unit of effort (CPUE) estimates for burbot sampled in five river sections during 1991.

Sampling Dates	Effort (Net-Nights)	300 -449 mm TL			450 - 799 mm TL			> 800 mm TL			≥ 450 mm TL		
		Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPUE	SE
Tolovana River Section													
Marking Event													
6/12 - 6/19	570	37	0.07	0.01	595	1.04	0.06	1	<0.01	<0.01	596	1.05	0.06
Recapture Event													
6/26 - 7/03	568	39	0.07	0.01	235	0.41	0.03	2	<0.01	<0.01	237	0.42	0.03
Both Events													
6/12 - 7/03	1,138	76	0.07	0.01	830	0.73	0.03	3	<0.01	<0.01	833	0.73	0.03
Tanana River Section													
7/11 - 7/12 7/16 - 7/17	310	97	0.31	0.04	247	0.80	0.07	3	0.01	0.01	250	0.81	0.07
Nenana River Section													
8/20 - 8/23	242	67	0.28	0.04	147	0.61	0.07	13	0.05	0.02	160	0.66	0.07
Chena River Section													
Marking Event													
8/27 - 8/30	268	35	0.13	0.03	218	0.81	0.09	0	0	0	218	0.81	0.09
Recapture Event													
9/04 - 9/07	248	28	0.11	0.03	171	0.69	0.08	3	0.01	0.01	174	0.70	0.08
Both Events													
8/27 - 9/07	516	63	0.12	0.02	389	0.75	0.06	3	<0.01	<0.01	392	0.76	0.06
Yukon River Section													
10/1 - 10/4	173	1	<0.01	<0.01	78	0.45	0.06	32	0.19	0.03	110	0.64	0.07

Table 8. Mean length estimates of burbot sampled in six river sections during 1991.

Sample Section (Dates)	Length Range (mm TL)	<450 mm TL			450 - 800 mm TL			>800 mm TL			All >450 mm TL		
		n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE
					Goldstream Creek Section								
4/23 - 5/08	271 - 805	3	380	5	18	619	19	1	805	ID[a]	19	628	18
					Tolovana River Section								
6/12 - 6/19	299 - 807	37	398	8	595	577	3	1	807	ND[b]	596	577	3
6/26 - 7/03	249 - 875	39	373	8	235	558	4	2	853	23	237	560	4
Both Events	249 - 875	76	385	6	830	571	2	3	837	20	833	572	2
					Tanana River Section								
7/11 - 7/12 7/16 - 7/17	238 - 922	97	386	5	247	530	4	3	893	19	250	534	4
					Nenana River Section								
8/20 - 8/23	290 - 903	67	380	5	147	574	7	13	842	9	160	596	6
					Chena River Section								
8/27 - 8/30	288 - 785	33	385	8	209	562	5	0	ND	ND	209	562	5
9/04 - 9/07	295 - 895	28	382	9	171	565	5	3	850	27	174	569	5
Both Events	288 - 895	61	384	6	380	563	3	3	850	27	383	565	3
					Yukon River Section								
10/1 - 10/4	400 - 1,070	1	400	ND	78	691	9	32	893	12	110	750	8

[a] Insufficient data.
[b] No data.

Table 9. Catch-per-unit of effort (CPUE) estimates for burbot sampled in four river sections, 1986-1991.

Year	Sampling Dates	River km Sampled	Net-Nights	Catch[a] Large	Catch[a] Small	CPUE[b] Large	SE	CPUE[b] Small	SE
				Tolovana River Section					
1988	9/14 - 9/21	37-78	192	214	5	1.11	0.10	0.03	0.01
1989	7/29 - 8/1	0-43	121	95	8	0.79	0.09	0.07	0.02
1991	6/12 - 6/19	0-48	570	596	37	1.05	0.06	0.07	0.01
1991	6/26 - 7/3	0-48	568	237	39	0.42	0.03	0.07	0.01
				Chena River Section					
1988	9/6 - 9/9	0-24	88	65	23	0.90	0.13	0.32	0.08
1989	6/27 - 6/30	0-40	120	73	30	0.61	0.09	0.25	0.06
1990	6/12 - 6/15	0-24	232	16	14	0.07	0.02	0.06	0.02
1990	8/21 - 8/24	0-24	204	84	42	0.41	0.06	0.21	0.04
1990	8/27 - 8/31	0-24	203	206	60	1.01	0.11	0.30	0.04
1990	9/6 - 9/7	0-24	73	88	24	1.21	0.09	0.33	0.03
1990	9/27 - 9/28	0-24	80	66	11	0.83	0.05	0.14	0.03
1991	8/27 - 8/30	0-24	268	218	35	0.81	0.09	0.13	0.03
1991	9/4 - 9/7	0-24	248	174	28	0.70	0.08	0.11	0.03
				Tanana River Section					
1986	7/29 - 8/15	334-377	466	361	180	0.77	ND[d]	0.39	ND[d]
1987	7/22 - 7/25	339-378	77	50	25	0.65	0.09	0.33	0.02
1987	7/28 - 7/31	339-378	106	83	76	0.78	0.09	0.72	0.10
1987	8/4 - 8/7	339-378	79	53	31	0.67	0.10	0.39	0.08
1987	8/18 - 8/21	339-378	183	195	49	1.07	0.11	0.27	0.05
1988	7/6 - 7/9	312-376	268	143	159	0.53	0.05	0.59	0.05
1989	6/13 - 6/16	317-374	237	131	137	0.55	0.05	0.58	0.06
1990	8/14 - 8/16	344-376	90	100	44	1.11	0.12	0.49	0.10
1991	7/11 - 7/17	336-360	310	250	97	0.81	0.07	0.31	0.04
				Yukon River Section					
1988	8/24 - 8/27	(-22)-56[c]	239	141	2	0.59	0.06	<0.01	<0.01
1989	7/16 - 7/18	(-242)-(-203)[c]	170	42	11	0.25	0.05	0.06	0.02
1991	10/1 - 10/4	(-24)-0[c]	173	110	1	0.64	0.07	<0.01	<0.01

[a] Large burbot are 450 mm total length and larger, and small burbot are less than 450 mm total length.

[b] Catch-per-unit of effort is defined as burbot per net-night.

[c] River kilometers were measured either upstream or downstream from the Dalton Highway Bridge.

[d] No data available.

Table 10. Mean length estimates for burbot sampled in four river sections, 1986-1991.

Year	Sampling Dates	River km Sampled	Length Range (mm TL)	Catch[a] Large	Catch[a] Small	Mean Length (mm TL) Large	SE	Small	SE
			Tolovana River Section						
1988	9/14 - 9/21	37-78	275-952	214	5	660	8	422	16
1989	7/29 - 8/1	0-43	280-875	95	8	605	11	370	8
1991	6/12 - 6/19	0-48	299-807	596	37	577	3	398	8
1991	6/26 - 7/3	0-48	245-875	237	39	560	4	373	8
			Chena River Section						
1988	9/6 - 9/9	0-24	306-754	65	23	557	8	394	8
1989	6/27 - 6/30	0-40	295-802	73	30	571	10	366	6
1990	6/12 - 6/15	0-24	265-600	16	14	510	12	375	14
1990	8/21 - 8/24	0-24	302-873	84	42	544	8	400	7
1990	8/27 - 8/31	0-24	294-852	206	60	556	5	409	5
1990	9/6 - 9/7	0-24	316-762	88	24	554	7	391	9
1990	9/27 - 9/28	0-24	315-905	66	11	564	9	381	18
1991	8/27 - 8/30	0-24	288-785	218	35	562	5	385	8
1991	9/4 - 9/7	0-24	295-895	174	28	569	5	382	9
			Tanana River Section						
1986	7/29 - 8/15	334-377	258-922	361	180	574	5	385	3
1987	7/22 - 8/21	339-378	304-1,079	425	217	583	6	398	2
1988	7/6 - 7/9	312-376	235-855	143	159	523	6	388	3
1989	6/13 - 6/16	317-374	278-895	131	137	549	8	381	4
1990	8/14 - 8/16	344-376	300-900	100	44	553	8	393	6
1991	7/11 - 7/17	336-360	238-922	250	97	534	4	386	5
			Yukon River Section						
1988	8/24 - 8/27	(-22)-56[c]	311-1,000	141	2	656	11	370	42
1989	7/16 - 7/18	(-242)-(-203)[c]	209-970	42	11	660	8	331	25
1991	10/1 - 10/4	(-24)-0[c]	400-1,070	110	1	750	8	400	ID[b]

[a] Large burbot are 450 mm total length and larger, and small burbot are less than 450 mm total length.
[b] Insufficient data.
[c] River kilometers were measured either upstream or downstream from the Dalton Highway Bridge.

(CPUE = 1.21; Table 9). During four separate sampling events in the Tanana River section during 1987, catch rates were consistent for three periods during mid-July through early-August (CPUE = 0.65, 0.78 and 0.67, respectively), but were substantially higher by mid-August (CPUE = 1.07; Table 9). Similarly, the same pattern was noted in this section during a sampling event conducted in mid-July of 1991, and one conducted during mid-August of 1990 (CPUE = 0.81 and 1.11, respectively; Table 9). Similar catch patterns (high catches during spring and fall and low during summer) are noted in many lacustrine burbot populations (Parker et al. 1988) as well, and these fluctuations also seem to vary by lake. Thus, if CPUE estimates are to be used to assess relative abundance for a given section, these seasonal fluctuations must be understood.

These seasonal variations in catch rates have important implications when conducting mark-recapture experiments to estimate actual abundance. When catch rates are low, a great deal of fishing effort must be expended to obtain an adequate sample size. This may be cost-prohibitive in many cases. However, care must be taken when sampling during the spring and fall such that significant movements are not occurring during the sampling period, which will bias the estimate. Significant movements were noted during the experiment in the Tolovana River section. Catches were high during the marking event and an adequate sample was collected. During the recapture event, however, catches dropped off dramatically and too few samples were collected to calculate an accurate estimate of abundance. In addition, movements of recaptured fish indicated that many of the marked fish were migrating downstream from the section. The tests for size-selectivity indicated that burbot captured during the second event were smaller than those captured during the first event. The movement behavior of recaptured burbot indicated that the observed difference in length frequency distributions between sampling events was a result of size-selective emigration as opposed to a difference in catchability. The modified estimator of Bernard (Evenson 1988) should have relieved some of the bias associated with emigration from the study area. However, two burbot were documented as moving a distance grater than the length of one section division (16 km in this experiment; Figure 4). This sort of movement behavior would bias this estimate high. Bias associated with size-selectivity could only be corrected for by size-stratification, for which a large number of recaptured burbot are required.

The mark-recapture experiment conducted in the Chena River section was conducted during a period of high CPUE, but was not biased by excessive movements out of the study section. Consequently, relatively large samples were collected in a short period during each sampling event, and a reasonably accurate estimate was obtained (relative precision = 38%).

The purpose of sampling in the Yukon River section was to determine if the same kind of seasonal fluctuations in CPUE occur in the Yukon River as occurs in many of the Tanana River sections. One sampling event was conducted in this section during late-August of 1988 and one in a separate section of the Yukon River during mid-July of 1989. Catches during the 1991 sampling event were substantially higher (CPUE = 0.64) than were catches from a sampling event conducted during July, 1989 (CPUE = 0.25), and slightly higher than from a sampling event conducted during August, 1988 (CPUE = 0.59; Table 9). Thus, it appears that the pattern of catch fluctuations in the Yukon River is similar to those observed in the Tanana River and its tributaries.

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APPENDIX A

Appendix A. Description of river sections sampled in 1991.

TOLOVANA RIVER (64°55′ N, 149°45′ W). This section was 48 km in length. The section began at the confluence of the Tolovana and Tanana rivers and extended upstream to the confluence of the Tolovana River and Swanneck Slough. There is no road access to this area. This section lies in the southern end of Minto Flats State Game Refuge. Annual harvest of burbot in this area has ranged from 0 to 132 burbot annually since 1977 (Mills 1979-1991). This section was also sampled in 1989 (Evenson 1990).

NENANA RIVER (64°30′ N, 149°10′ W). This section was 24 km in length. The section began at the confluence of the Nenana River and the Tanana River and extended upstream to the confluence of the Teklanika River. Seventeenmile Slough flows into the Nenana River at river kilometer nine (measured upstream from the mouth of the Nenana River). The lower 15 km of this slough were also sampled. Annual harvests in this area have ranged from 0 to 68 burbot since 1984 (Mills 1985-1991). The town of Nenana, Alaska is located at the confluence of the Nenana and Tanana rivers, and river access can be acquired there. This section had not previously been sampled.

TANANA RIVER (64°45′ N, 148°0′ W). This section was 24 km in length. The section began at river kilometer 336 (measured upstream from the mouth of the Tanana River) and extended upstream to the confluence of the Chena River. The town of Fairbanks, Alaska is in close proximity to this section. A state-maintained campground and boat launching facility are located within this section. A substantial year-round fishery occurs within this section. This section has been sampled annually since 1983 (Hallberg 1984-1986; Hallberg et al. 1987; Evenson 1988-1991).

CHENA RIVER (64°50′ N, 147°50′ W). This section was 24 km in length. The section began at the confluence of the Chena and Tanana rivers and extended 24 km upstream. This portion of the river flows through the town of Fairbanks, Alaska. Numerous access points and boat launching facilities exist within this section. A substantial year-round fishery occurs within this section. Harvests have ranged from 149 to 2,065 burbot annually since 1977 (Mills 1978-1991). This section has been sampled annually since 1988 (Evenson 1989-1991).

YUKON RIVER (65°50′ N, 149°45′W). This section was 24 km in length. The section began 24 km downstream from the Dalton Highway Bridge and extended upstream to the bridge. A boat launching facility exists in the vicinity of the bridge. Harvest in this specific area is unknown, although total harvest in the Yukon River has ranged from 18-509 burbot since 1977 (Mills 1991). This section was also sampled in 1988 (Evenson 1989).

GOLDSTREAM CREEK 64°50′ N, 148°50′ W). This section was 6 km in length. Most all burbot were caught in a large fyke trap set 1 km downstream from the confluence of the Minto Lakes outlet. There is no road access to this immediate area. No harvest estimates are available for this specific area. This section had not been sampled previously.

APPENDIX B

Appendix B. Statistical tests used to analyze mark-recapture data for significant bias due to gear selectivity by length.

Test A. Kolmogorov-Smirnov two sample test comparing the distributions of the lengths of all fish that were marked during the marking sample and all marked fish that were collected during the recapture sample; and,

Test B. Kolmogorov-Smirnov two sample test comparing the distributions of the lengths of all fish that were captured during the marking sample and all fish that were collected during the recapture sample.

The null hypothesis is no difference between the distributions of lengths for Test A or for Test B.

For these two tests there are four possible outcomes:

Case I:

Accept $H_o(A)$ Accept $H_o(B)$

There is no size-selectivity during the first sample (when burbot were marked) or during the second sample (when burbot were collected).

Case II:

Accept $H_o(A)$ Reject $H_o(B)$

There is no size-selectivity during the second sample but there is size-selectivity during the first sample.

Case III:

Reject $H_o(A)$ Accept $H_o(B)$

There is size-selectivity during both samples.

Case IV:

Reject $H_o(A)$ Reject $H_o(B)$

There is size-selectivity during the second sample; the status of size-selectivity during the first sample is unknown.

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Depending on the outcome of the tests, the following procedures will be used to estimate the abundance of the population:

Case I: Calculate one unstratified estimate of abundance, and pool lengths from both samples to improve precision of proportions in estimates of compositions.

Case II: Calculate one unstratified estimate of abundance, and only use lengths from the second sample to estimate proportions in compositions.

Case III: Completely stratify both samples, and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Pool lengths from both samples to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data.

Case IV: Completely stratify both samples and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Also, calculate a single estimate of abundance without stratification.

Case IVa: If the stratified and unstratified estimates of abundance for the entire population are dissimilar, discard the unstratified estimate. Only use the lengths the second sample to estimate proportions in composition, and apply formulae to correct for size bias to data from the second sample.

Case IVb: If the stratified and unstratified estimates of abundance for the entire population are similar, discard the estimate with the larger variance. Only use the lengths from the first sample to estimate proportions in compositions, and do not apply formulae to correct for size bias.

To determine the appropriate breaks for length strata, a battery of R X C contingency table analyses were performed. Each table consisted of two rows corresponding to the number of recaptured and not recaptured fish. The number of columns varied between tests, and were comprised of two or more length categories.
